VENUS WINDS STUDY

IMAGE CATEGORIZATION FOR BEGINNERS
USING FITSLiberator v.3

Introduction

This document is intended for new Venus Image Analysts using ***FITSLiberator v.3***. It assumes that you have access to the *Venus Winds Wiki* so that (1) you can download images for analysis, (2) have installed the program on your computer, and (3) have downloaded the *FITSLiberator User Guide* PDF.

Software download http://www.spacetelescope.org/projects/fits_liberator/download_v30
User Guide: http://www.spacetelescope.org/static/projects/fits_liberator/v30files/userguide.pdf

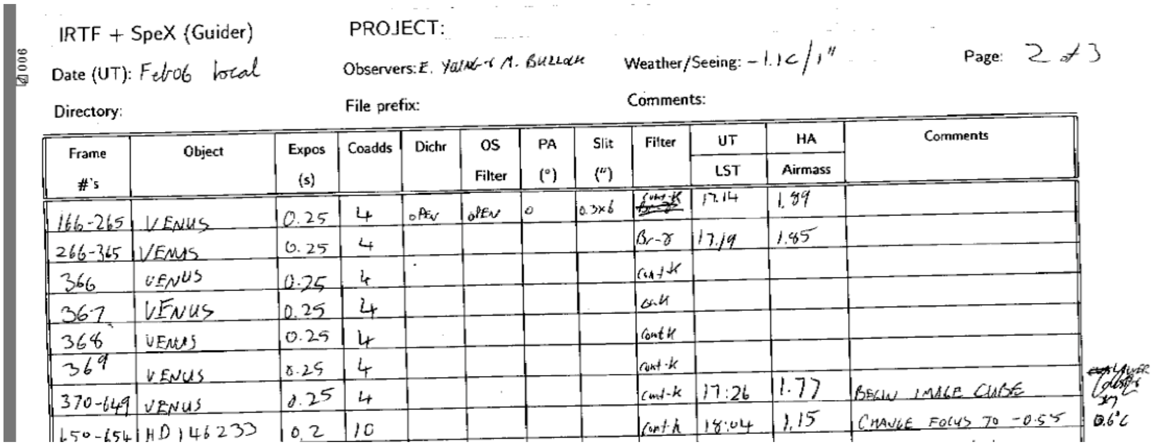
A Short Digression About FITS Images and Observer Logs

FITS is a standard format for recording and distributing astronomical images. The FITS images we will will be analyzing are produced at the NASA IRTF telescope located on Mauna Kea, Hawaii. The images are recorded by a camera whose charge-coupled device (CCD) located at the focal plane is sensitive to the infrared part of the spectrum. The CCD consists of a square array of light-sensitive picture elements (pixels; px) that is 512 px on a side. Each pixel stores a 16-bit binary integer that is approximately proportional to the light intensity falling on it, meaning that there are 65,536 possible *levels* (shades) of grey, ranging from pure black (-32,768) to pure white (32,767), an extraordinary dynamic range that permits distinguishing subtle details in the FITS image.

The FITS images with which we will be working are filtered to record light in several infrared bands, namely the *continuum K-band* (abbreviated *cont-K*) and the *Brackett-γ-line* (abbreviated *Br-γ* or *Br-gamma*).

Computer monitors typically display 8-bit greyscale images so it is important to retain as much of the dynamic range when the image is saved (in TIFF format) for further processing by a program such as Adobe Photoshop or GIMP.

One of the first tasks, before categorizing any images, is to examine the *observer log* for a particular run. The log contains, in compact form, much useful information about the conditions under which the images were recorded, including the object, when it was imaged, exposure and filter information, and comments regarding weather and seeing (see figure below for an excerpt).



IRTF + SpeX (Guider) PROJECT:

Date (UT): Feb06 local Observers: E. Young + M. Bullock Weather/Seeing: -1.1C / 1" Page: 2 of 3

Directory: File prefix: Comments:

Frame #'s	Object	Expos (s)	Coadds	Dichr	OS Filter	PA (°)	Slit (")	Filter	UT / LST	HA / Airmass	Comments
166-265	VENUS	0.25	4	OPEN	OPEN	0	0.3x6	Cont-K	17.14	1.89	
266-365	VENUS	0.25	4					Br-γ	17.19	1.85	
366	VENUS	0.25	4					Cont K			
367	VENUS	0.25	4					Cont K			
368	VENUS	0.25	4					Cont K			
369	VENUS	0.25	4					Cont-K			
370-649	VENUS	0.25	4					Cont-K	17:26	1.77	BEGIN IMAGE CUBE
650-654	HD 146233	0.2	10					Cont-K	18:04	1.15	CHANGE FOCUS TO -0.55

0.6°C

A short definition of observer log terms is found in Table 1.

TABLE 1 -- DEFINITION OF OBSERVER LOG TERMS	
Weather/Seeing	Temperature; clouds; estimate of seeing
Frame #s	Sequential image ID
Object	(See discussion below)
Expos	Exposure (sec)
Coadds	
Dichr	
OS Filter	None (Open)
PA (°)	Position angle (Up = 0°)
Slit (")	Slit width (?)
Filter	Blank (none); *cont-K* (continuum–K); *Br-g*/*Br-γ* (Brackett gamma)
UT/LST	Universal Time (UTC)/Local Standard Time
HA Airmass	
Comments	Other pertinent comments

Typical entries in the Object column are: Sky Flat (or Flat) An exposure of the open sky near (but not including) Venus; Focus An exposure of (usually of star(s)) to focus the camera; Dark An exposure where the CCD is covered; Venus An exposure of the Venus disk; Cube A special.

Dark frames ("**darks**") are acquired with all light blocked to the CCD to record pixels that are "live", at various level values, from residual noise inherent to all CCDs and "dead" pixels that have no signal at all. Live pixels can be subtracted from an image later with digital processing techniques.

Flat frames (or "**Sky flats**") are designed to record background illumination from multiple causes (e.g., airglow and scattered light from the Moon) in areas of the sky that are near (but not including) Venus. Flats are used to subtract these pixel levels from frames of Venus.

Preliminaries

The best way to gain experience with ***FITSLiberator*** is to analyze some image files described in the following section of this document. We first need to download images with which to experiment while learning to run ***FITSLiberator v.3***.

Step 1: Open the *Venus Winds Wiki* homepage

Scroll down to the Data Download & Upload section; click on Raw Images> *File:Venus Date Assignments.xls* to get the spreadsheet. Raw Images contains links, each of which points to a collection of image files for a particular observation run, stored in a compressed archive (*.zip*) file. For example, the Feb 6 2006 link contains these entries:

06feb_logs.pdf	Observer logs
All_Feb_06_2006_images.zip	Compressed folder of FITS images
File:2006_02_06.xls	Spreadsheet of relevant data for the images

Step 2: Open the Venus Data Assignment List: *Venus_Date_Assignments.xls*

Find a data acquisition date where an analyst had already done image categorization. For example: *2006_02_06_Larry.xls* was done by Larry Stearns. We will use this file as an illustrative example of image categorization.

Step 3: Open *2006_02_06_Larry.xls*

This spreadsheet is in a standard format that is intended to catalog the significant features of the observation run. Some items are taken from the observer log and noted in the table at the top left: Weather/seeing notes; focusing targets; dark fields; flat fields; and comments about specific Venus images.

Before categorization, certain fields in the spreadsheet are empty. These fields are found in the top right of the spreadsheet in a table that gives numbers of images in each category and their quality designation (Cat 1's>, Cat 2's>, Cat 3's> for the Venus images). In the main body of the spreadsheet are rows designating each image (Image ID, Object, Comment, DATE, HR, MIN, SEC, and Category)

A17 | fx | 1

	A	B	C	D	E	F	G	H	I	J	K	L
1	Weather/Seeing:		1" Seeing									
2												
3		Object	Comment							Scattered		
4	Dark_2s	5	55	2hrs W of Venus, ditherPos1				Category	Flat Field	Light	De-Slit	Register
5	Dark_5s	10	50	2hrs W of Venus, ditherPos1 + 10"S			Cat 1's >	451				
6	Darks1	5	45	2hrs W of Venus, ditherPos1 + 5"S			Cat 2's >	475				
7	Eps_Lyrae1	10	10	Double star			Cat 3's >	497				
8	Focus star in M13	5	5	Focus star in M13			========	======				
9	HD 146233	5	5	G2Va solar analog				1423				
10	Sky Flats	305	45	Sky at Venus + 2degN								
11	Venus	1078	35	Sky at Venus + 2degN + 10"S								
12			55	Sky at Venus + 2degN + 5"S								
13			1078	Venus								
14			20	Venus + 2 deg N								
15	Image ID											
16	1423	1423	1403	DATE	HR	MIN	SEC	Category	Black	White		
17	1	Eps_Lyrae1	Double star	2/6/06	15	57	29.991696	3				
18	2	Eps_Lyrae1	Double star	2/6/06	15	57	35.506845	3				
19	3	Eps_Lyrae1	Double star	2/6/06	15	57	40.914089	3				
20	4	Eps_Lyrae1	Double star	2/6/06	15	57	46.319627	3				
21	5	Eps_Lyrae1	Double star	2/6/06	15	57	51.751239	3				
22	6	Eps_Lyrae1	Double star	2/6/06	15	57	57.175317	3				
23	7	Eps_Lyrae1	Double star	2/6/06	15	58	2.678313	3				

The top section of the spreadsheet provides a summary for later analysis of the different groups of images acquired. In this example, there are 1078 images of Venus out of a total of 1423. The others are images taken for focusing and "seeing" (e.g., "Eps_Lyrae1") as well as dark frames (e.g., "Darks1") and flat frames ("Sky Flats"). Data for each acquired image are in the scrolling area of the spreadsheet.

Scroll down to Image ID = 166, the first Venus image acquired during this run. At this date and time (in UTC), Larry has characterized the image as Category 1, the highest quality class.

13			1078	Venus						
14			20	Venus + 2 deg N						
15	Image ID									
16	1423	1423	1403	DATE	HR	MIN	SEC	Category	Black	White
179	163	Focus star in M13	Focus star in M13	2/6/06	17	6	38.928027	3		
180	164	Focus star in M13	Focus star in M13	2/6/06	17	6	51.370189	3		
181	165	Focus star in M13	Focus star in M13	2/6/06	17	7	3.813954	3		
182	166	Venus	Venus	2/6/06	17	13	6.056898	1	13951	29695
183	167	Venus	Venus	2/6/06	17	13	8.561538	1		

Scroll down to Image ID = 266. Note that the Category is now 3, the worst quality (and generally unusable) class.

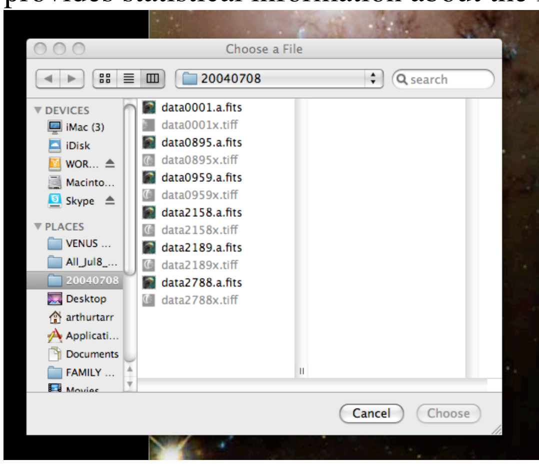
14			20	Venus + 2 deg N						
15	Image ID									
16	1423	1423	1403	DATE	HR	MIN	SEC	Category	Black	White
277	261	Venus	Venus	2/6/06	17	17	59.752005	1		
278	262	Venus	Venus	2/6/06	17	18	2.321060	1		
279	263	Venus	Venus	2/6/06	17	18	4.879125	1		
280	264	Venus	Venus	2/6/06	17	18	7.376131	1		
281	265	Venus	Venus	2/6/06	17	18	9.951582	1		
282	266	Venus	Venus	2/6/06	17	18	35.373175	3		
283	267	Venus	Venus	2/6/06	17	18	38.029432	3		
284	268	Venus	Venus	2/6/06	17	18	40.540489	3		

An Introduction to Using FITSLiberator v.3

Download *All_Jul_9_2004_images.zip* to a large capacity disk drive and uncompress the archive file, then look at examples using the program ***FITSLiberator***.

The ***FITSLiberator*** program is a powerful program for analyzing FITS images. After the program has been loaded, it will be helpful to read the **User Guide** (*UserGuide.pdf*). Initiate ***FITSLiberator***. At this stage, accept all default parameter values. In this introduction, we will use images from the 9 July 2004 observation run.

Click on a FITS format (.fits) filename, for example: *data0895.a.fits* (Fig. 1). This action opens the FITS image file, displays it in the Liberator Graphical User Interface, and provides statistical information about the image (Fig. 2).



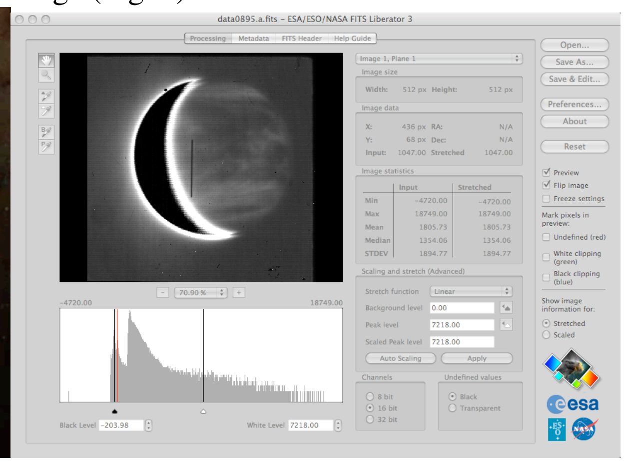
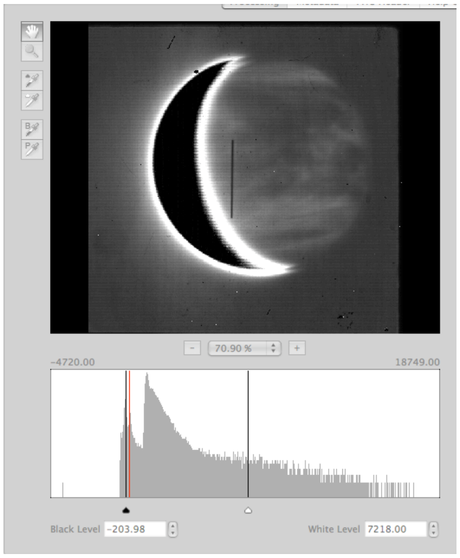


Fig. 1 Open a file

Fig. 2 Display of Liberator Graphical User Interface

The upper left part of the window in Fig. 2 displays an **8-bit** greyscale image of the file. At the lower left is a histogram of the distribution of **16-bit** greyscale values. The number of pixels at each greyscale value is represented by the height of the vertical grey bars. Pure black is at the left edge of the histogram, pure white at the right edge. The right half of the Graphical User Interface in Fig. 2 is devoted to displays of characteristics of various aspects of the image and tools useful for manipulating the image. We will leave most of these options at their default values for the time being.



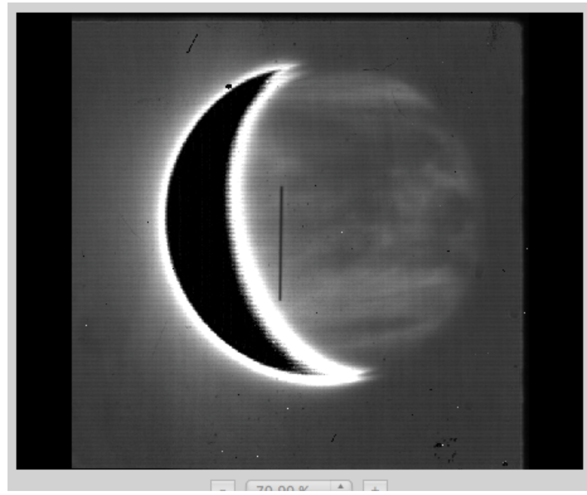


Fig. 3 Image display and histogram

Fig. 4 Detail of image window

Referring just to the image display and histogram part of the interface (Fig. 3) and the enlarged image window (Fig. 4), we notice that the cloud patterns are faintly visible and the nightside limb is delimited reasonably well. The dayside crescent is so bright that it saturates the CCD pixels (set to black). The crescent also creates zones of blown-out highlights along the terminator and scatters light into the sky to the immediate left of the crescent. Further, we note that the sky surrounding Venus is not completely black as we might expect. Referring to Fig. 5, we note that the image window does not display all the levels in the pure black to pure white range. The levels actually displayed in Fig. 4 are those between the black and white sliders (indicated by a black and white triangles below the histogram) and the numerical values of the Black Level (-203.98) and White Level (7218.00) displayed. The vertical red line indicates the Zero Level (0.00).

Whatever the source of the background glow and glare, we need to increase the contrast of the cloud features. This is accomplished by adjusting the black slider and the white slider levels to narrow the range of pixel levels so that the contrast is improved in the adjusted image. Move the sliders to see the effect on the image.

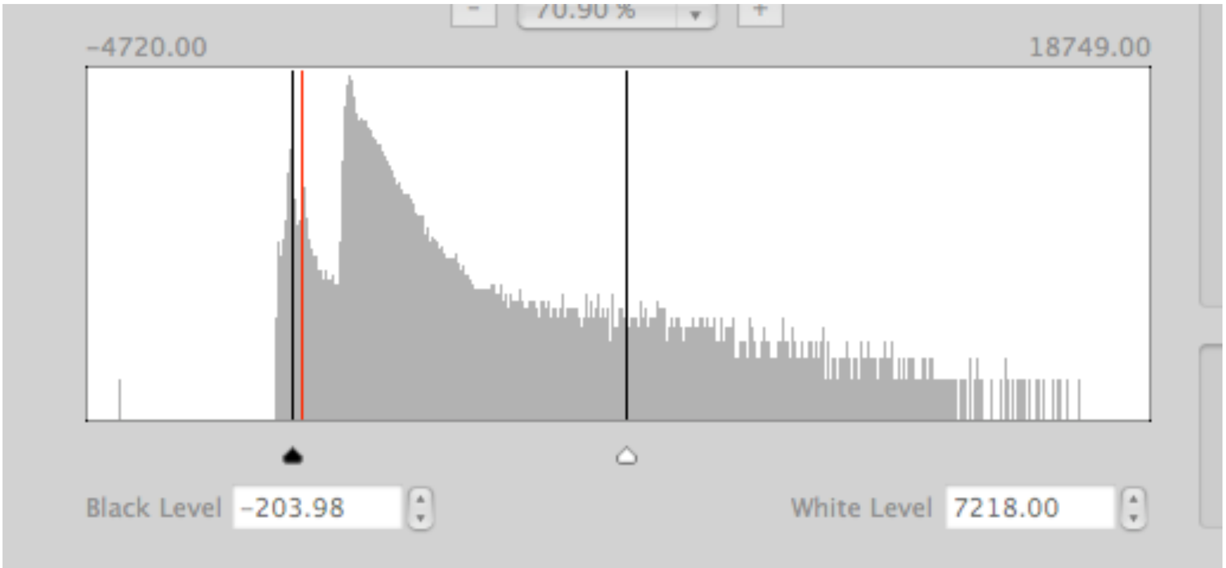


Fig. 5 Closeup of image histogram before adjusting the black and white levels.

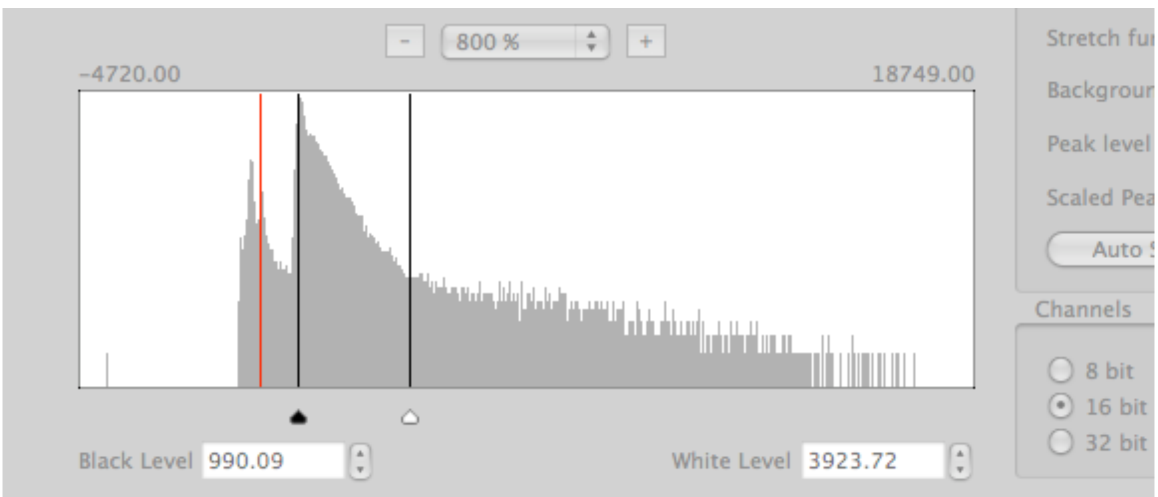


Fig. 6 Image histogram following adjustment of the black and white sliders.

Fig. 6 shows that the range of levels is now 990.9 – 3924.72, cutting off some of the white glare and deepening the sky background. Note that the range is now between the largest black level peak and a white level where the histogram values change slope. This choice was made by trial and error. Later, we will employ more sophsticated techniques to optimize the final display.

The interface window now looks like Fig. 7. Adjusting the black and white level sliders has increased the contrast of the cloud features on the nightside of Venus and sharpened the nightside limb (Fig. 8). Although the flaring around the dark crescent has increased visibly, little information has been lost in the nightside where clarity counts.

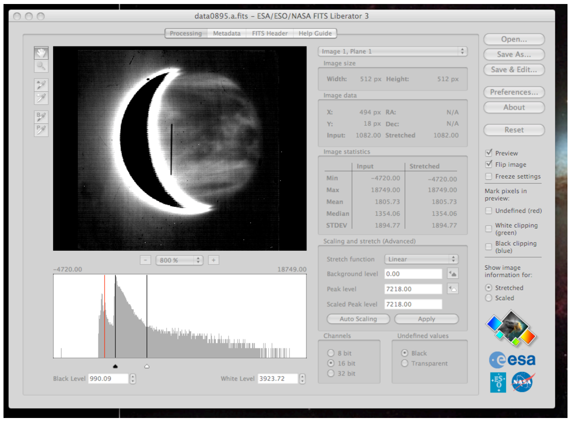


Fig. 7 New interface window

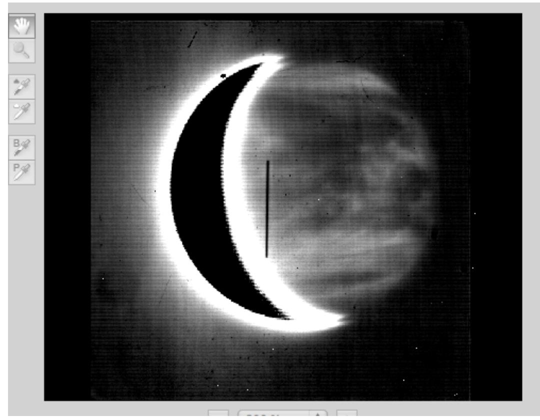


Fig. 8 Improved contrast of clouds in enhanced image

This simple technique allows an analyst to quickly categorize the quality of the images. In the particular case of this image, the category is one degree better than might have been attributed to the raw image (Fig. 3). Enlarging the scale of the image window (Fig. 9) shows extraordinary detail in the clouds of the Southern Hemisphere. The dark features are high level clouds blocking infrared emission from below. Note also the apparent doubling of the overexposed Southern "horn" of the illuminated hemisphere.

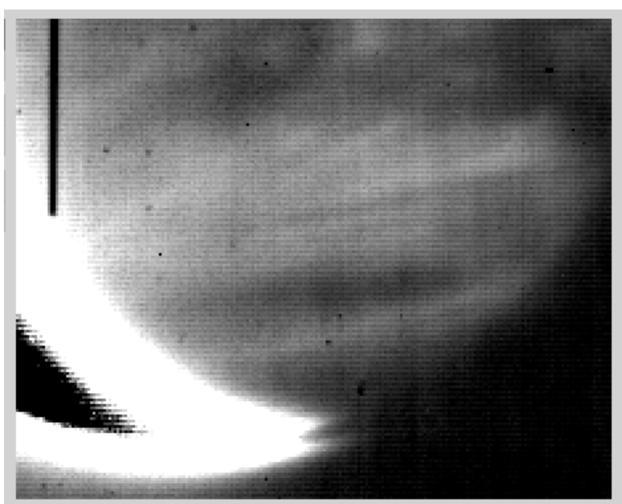


Fig. 9 Enlargement of the image window shown in Fig. 8.

Image Quality and Corresponding Categories

Our task is to evaluate the many thousands of images of Venus against image quality criteria. The characteristics that serve to make an assessment of image quality are:

Resolution is a measure of the *smallest* spatial feature on the image; theoretically, that is one pixel. The angular width of one pixel is given by the *plate scale* of the CCD, in units

of *arcsec per pixel*. The value for the IRTF CCD is 0.114 arcsec/px; this value was determined by measuring the distance of a double star of known angular separation.

Contrast is the *difference* in levels between adjacent features. High contrast is needed especially to distinguish edges of features such as the nightside limb and the dark clouds from lighter background.

Sharpness and **clarity** are qualitative terms that are nominally related to resolution and contrast but also to observational conditions, such as "seeing" (i.e., the amount of blurring due to atmospheric turbulence) and water vapor in Earth's atmosphere that may attenuate the 2.04-2.35μm infrared passband.

The three image quality categories we use are:

Category 1: **Highest quality** Category 1 is characterized by clarity and high contrast of the Venusian cloud shapes and the nightside limb which requires a dark sky field around Venus. This category implies minimal interference from moonlight and terrestrial atmospheric sources such as terrestrial sky glow and clouds.

Category 2: **Intermediate quality** Compared with Category 1, Category 2 is characterized by lower clarity (possibly due to deteriorating seeing) and/or lower contrast, possibly due to minor sky glow, water vapor absorption, thin terrestrial clouds, or haze originating above the telescope.

Category 3: **Lowest quality** Category 3 images are characterized by little or no evidence of Venusian clouds, a condition caused by bad seeing, terrestrial clouds, sky glow, and/or elevated levels of humidity at or above the telescope site. The bright sunlit crescent may appear normal, but the nightside limb is often not observed under such conditions.

Images that do not show discernable clouds and limb on the nightside are automatically assigned Category 3 even if criteria of excellent resolution, contrast, and absence of interference from turbulence, haze, or scattered light from Moon and sky are met. **Frames acquired for focusing, sky frames, and dark frames are also Category 3.**

Examples of Image Quality

Image quality may appear to change with astonishing rapidity. To illustrate, consider three images recorded between 18:33:05 and 18:33:57 UTC on 6 February 2006. In less than one minute, image *0839* changed from Category 3 to Category 1 (*0840*)and then to Category 2 (0844) as documented in the image categorization for that date (Fig. 10). We examine four examples.

14			20	Venus + 2 deg N						
15	Image ID									
16	1423	1423	1403	DATE	HR	MIN	SEC	Category	Black	White
853	837	Venus	Venus	2/6/06	18	33	0.661499	3		
854	838	Venus	Venus	2/6/06	18	33	3.164549	3		
855	839	Venus	Venus	2/6/06	18	33	5.777114	3		
856	840	Venus	Venus	2/6/06	18	33	46.655419	1	13951	37375
857	841	Venus	Venus	2/6/06	18	33	49.178853	1		
858	842	Venus	Venus	2/6/06	18	33	51.827183	1		
859	843	Venus	Venus	2/6/06	18	33	54.513730	1		
860	844	Venus	Venus	2/6/06	18	33	57.069615	2		
861	845	Venus	Venus	2/6/06	18	33	59.597792	2		
862	846	Venus	Venus	2/6/06	18	34	2.119488	2		

Fig. 10 Extract from 2006_02_06_Larry.xls *to illustrate rapid change from in image categories.*

Example 1: Image *im0839.a.fits* was recorded at 18:33:05 UTC. Fig. 11 and Fig. 12 show that the dark hemisphere displays no cloud detail and no dark limb although the illuminated crescent and terminator are clearly visible.

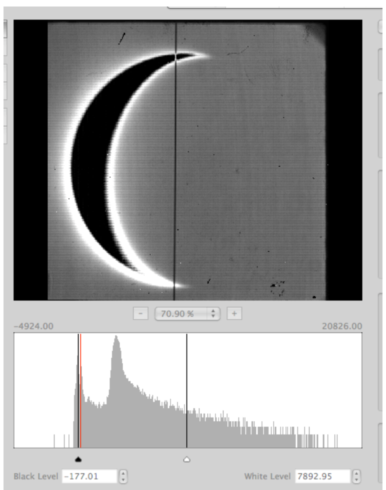


Fig. 11 Raw image im0839.a.fits

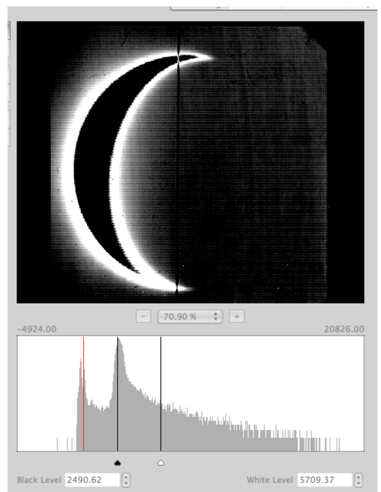


Fig. 12 Enhanced image im0839.a.fits

This is a Category 3 image but the reason is not obvious because it appears to be a high quality exposure. In addition, the histogram is similar to the one shown in Fig. 6 in terms of clarity and contrast. There seems to be no evidence of atmospheric interference, such as haze or clouds. It strains credulity that the observing conditions could have changed so fast.

The answer is found in the observer's log. Image *im0839.a.fits* was recorded with a *Br-γ* (Brackett-gamma) filter while the following image *im0840.a.fits* was recorded with a *cont-K* (continuum-K filter). The filter had been used in previous exposures of flat field frames and apparently was not switched out when exposures of Venus frames were begun.

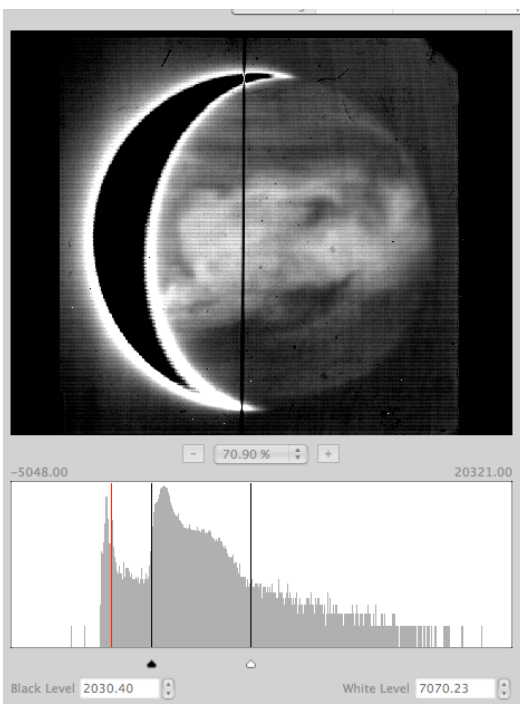
A Small Digression: Why are two filters used to image Venus?

A cursory examination of images exposed with the *cont-K* filter show relatively faint signatures of infrared emission originating beneath the cloud deck on the nightside

relative to the bright dayside hemisphere. The bright crescent of Venus saturates the CCD sensor (the crescent pixels have levels at the maximum permissable level and are set to black). This creates a "blooming" effect that expands the *apparent* radius of the dayside limb, caused by flaring of adjacent pixels in the CCD, illumination of the upper atmosphere of Venus and light scattered in Earth's atmosphere. Thus, efforts to locate the limb radius on *cont-K* images can only be reliably accomplished on the nightside and never on the dayside.

Not to dispair! Part of the blooming effect is due to the broad passband of the *cont-K* filter (roughly 2.04 μm and 2.35 μm at 80% transmission) which allows infrared emission originating with the γ transition (n=7 → n=4) of the ***Brackett series*** of excited atomic hydrogen. Imaging Venus with a narrow-band filter peaking at approximately 2.17 μm and digitally subtracting the pixel values from the corresponding *cont-K* image should, in principle, leave the longer wavelength infrared emissions from the clouds of Venus.

Example 2: Image *im0840.a.fits* was recorded at 18:33:47 UTC, 42 seconds later. The dark limb and the dark clouds silouetting the lower cloud deck are clearly evident (Fig. 13). This is an excellent Category 1 image.



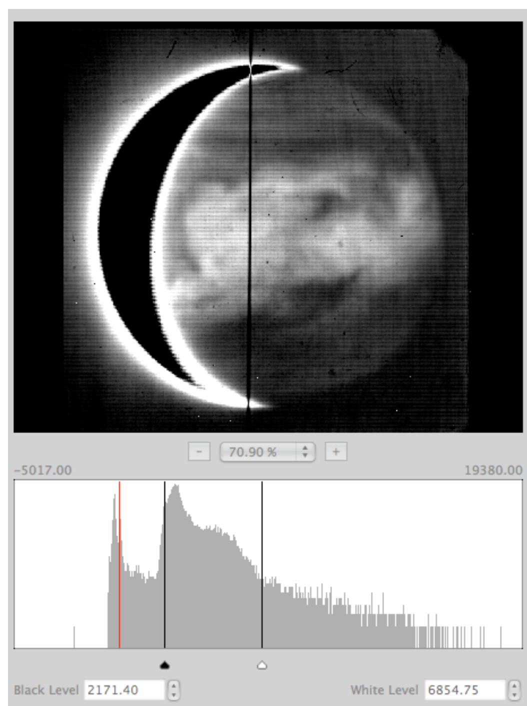


Fig. 13 Enhanced image im0840.a.fits *Fig. 14 Enhanced image im0844.a.fits*

Example 3: Ten seconds later, image *im0844.a.fits*, evaluated as Category 2, was recorded at 18:33:57 UTC and the image quality may have deteriorated very slightly as seen in Fig. 14. With image processing, this image might be elevated to Category 1.

Example 4: Much later, at 18:59:15.5 UTC, image *im1359.a.fits* was evaluated as Category 3. Processing the image in the same manner as the two preceding images, yields Fig. 15. The histogram is virtually identical to the histograms in Fig. 13 and Fig. 14. The distribution of light and dark grey shades has not changed so the conclusion is that the "seeing" has degraded enough to blur the edges between light and dark features. In other words, the overall sharpness and clarity of the image suffered. Even though the cloud features are not as sharp as the two earlier images, the nightside limb is clear and numerous cloud features can be identified in the processed image. This evaluation for this image is should be Category 2, not Category 3.

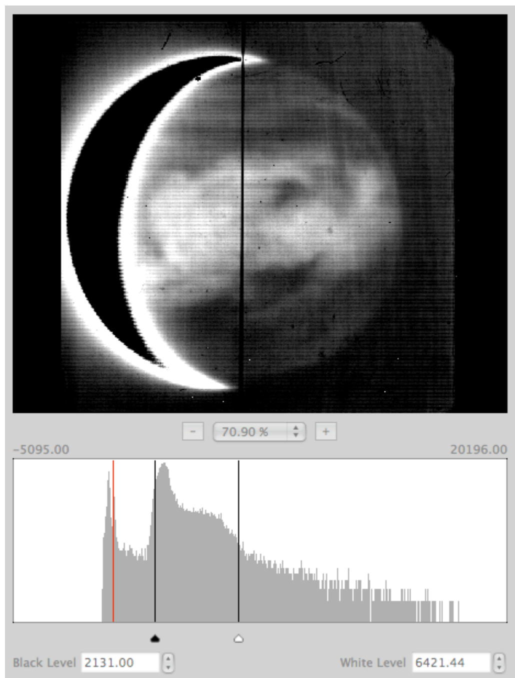


Fig. 15. *Enhanced image im1359.a.fits*

CONCLUSION

With practice, it should be possible to quickly categorize images into the three Categories. In addition, it may be possible in the future to analyze some higher-quality Category 2 images. ***Nevertheless, it is important to remember that identification of Category 1 images is the goal for further analysis!***